Ryerson University

Faculty of Engineering & Architectural Science

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Course Title	Signals and Systems I
Semester/Year	Fall 2022
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Section No.	12
Group No.	N/A
Submission Date	2022-11-13
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Lab/Tut Assignment NO.	4

Assignment Title	**Fourier Transforms: Properties and Applications**

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(Note: remove the first 4 digits from your student ID)

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Procedures

a) Complete Problems A.1 to A.6

Problem A.1 [**2 Marks**] For the signal $x(t)$ shown in Figure (1), compute and plot $z(t) = x(t) * x(t)$.

Problem A.2 [**2 Marks**] Using MATLAB, calculate $Z(\omega) = X(\omega)X(\omega)$.

Problem A.3 [**3 Marks**] Plot the magnitude- and phase-spectra of $z(t)$.

Problem A.4 [**3 Marks**] Compute $z(t)$ using **time-domain and frequency-domain operations** implemented in MATLAB. Plot both results and compare with the analytic result you determined in Problem A.1. Determine the appropriate time indices for proper labelling of the time-domain plots of $z(t)$. How do the results you generated in MATLAB using time- and frequency-domain operations compare with the analytic result you computed in Problem A.1? Explain which property of the Fourier Transform you have demonstrated.

Problem A.5 [**3 Marks**] Change the width of the pulse $x(t)$ to 5 while keeping the total length at $N = 100$. Compute the Fourier Transform of the narrower pulse and plot the corresponding magnitude- and phase-spectra. Repeat for a pulse width of 25. Explain the observed differences from the comparison of the frequency spectra generated by the three pulses with different pulse-widths. Explain which property of the Fourier Transform you have demonstrated.

Problem A.6 [**3 Marks**] Let $w_+(t) = x(t)e^{j(\pi/3)t}$ where $x(t)$ is the original pulse of pulse-width 10 shown in Figure (1). Using MATLAB compute and plot the magnitude- and phase-spectra of $w_+(t)$. Compare the frequency spectra result with those you generated in Problem A.3 and comment on the observed differences. Repeat for $w_-(t) = x(t)e^{-j(\pi/3)t}$ and $w_c(t) = x(t)\cos(\pi/3)t$. Explain which property of the Fourier Transform you have demonstrated.

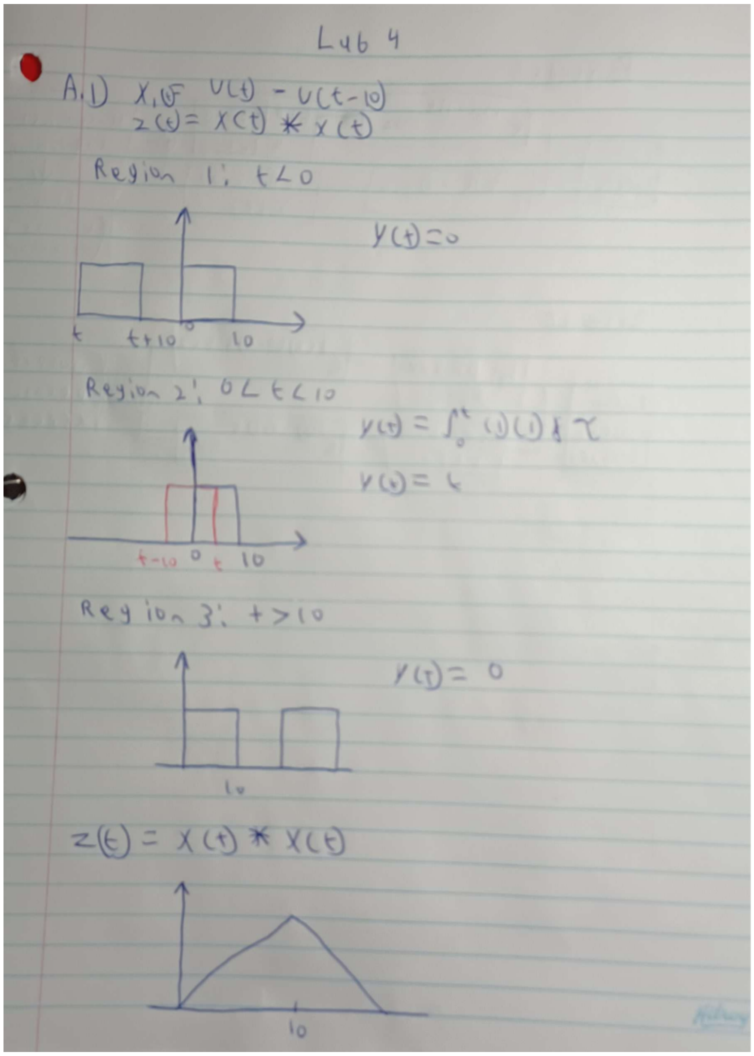
b) Complete Problem B.1

Study the frequency-domain (magnitude only) characteristics of the signal `xspeech`, the lowpass filters defined by `hLPF2000` and `hLPF2500`, and the transmission channel defined by `hChannel`. Design a coding system that will allow the transmission of the signal `xspeech` over the channel. Also design the corresponding decoder to recover `xspeech` from the channel output. Implement both the coder and the decoder in MATLAB. Provide block diagrams of the coder and the decoder you designed and explain the rationale of your design.
You can listen to the speech signals generated at any given point of your decoder or decoder design using the command `sound(xaudio,32000)` where `xaudio` is the data array you want to listen to.

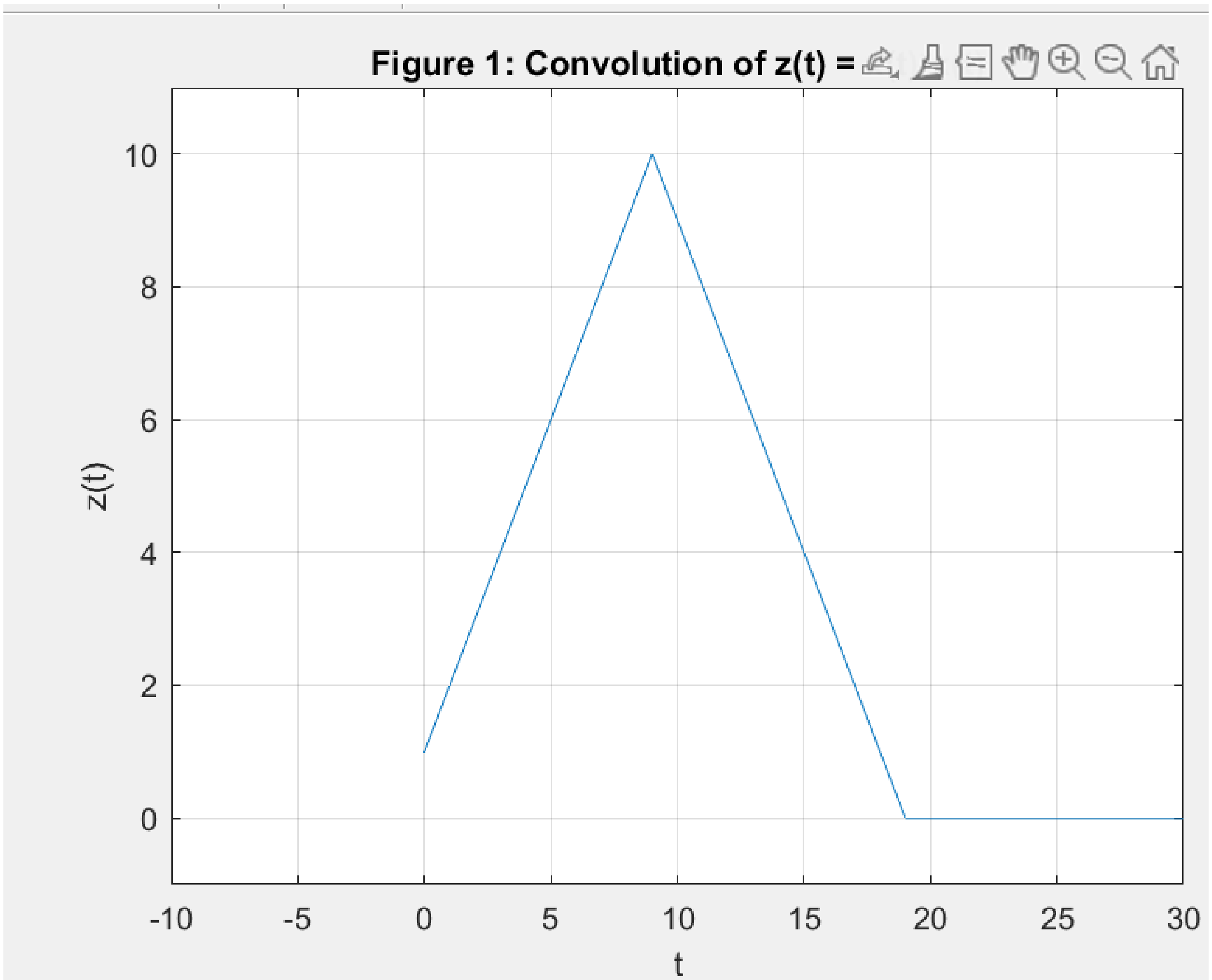
4. Results

<u>Assignment A:</u>

<u>A.1)</u>




```
N = 100;
PulseWidth = 10;
x = [ones(1,PulseWidth), zeros(1,N-PulseWidth)];
z = conv(x,x);
t2 = [0:1:2*(N-1)];
figure;
plot(t2,z);
grid on;
axis([-10,30,-1,11])
xlabel('t');
ylabel('z(t)');
title('Figure 1: Convolution of z(t) = x(t)*x(t)');
```

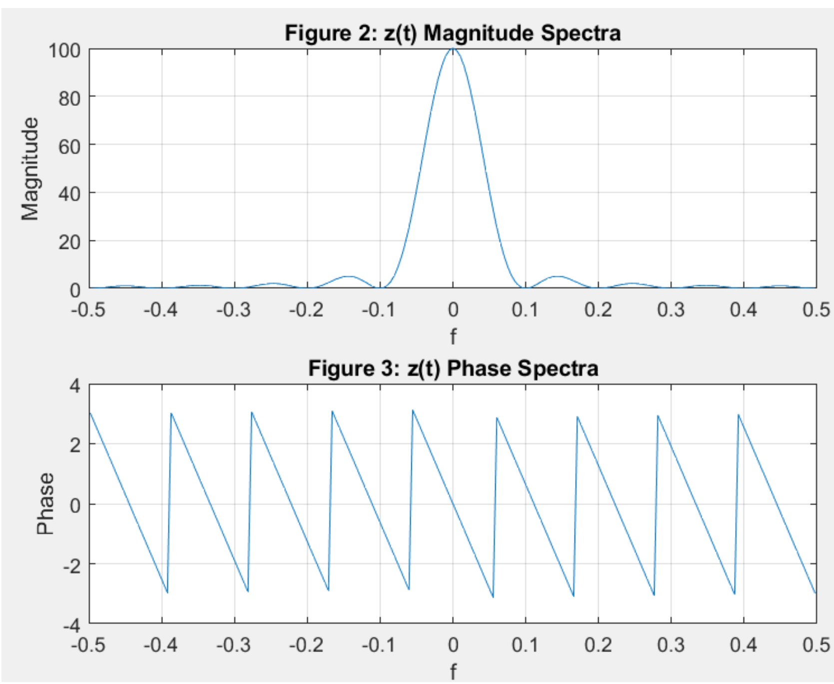


A.2)

```
N = 100;
PulseWidth = 10;
t = [0:1:(N-1)];
x = [ones(1,PulseWidth), zeros(1,N-PulseWidth)];
z = conv(x,x);
Xw = fft(z);
f = [-(N/2):1:(N/2)-1]*(1/N);
w = 2*pi*f;
%Zw = (Xw).*(Xw);
```

A.3)

```
N = 100;
PulseWidth = 10;
x = [ones(1,PulseWidth), zeros(1,N-PulseWidth)];
z = conv(x,x);
Zf = fft(z);
f = [-(N-1):1:(N-1)].*1/(2*N - 1);
figure(2);
subplot(2, 1, 1);
plot(f, fftshift (abs (Zf)));
xlabel('f');
ylabel('Magnitude');
title('Figure 2: z(t) Magnitude Spectra');
grid on;
subplot(2, 1, 2);
plot(f, fftshift (angle(Zf)));
xlabel('f');
ylabel('Phase');
title('Figure 3: z(t) Phase Spectra');
grid on;
```



A.4)

```
N = 100;
PulseWidth = 10;
x = [ones(1,PulseWidth), zeros(1,N-PulseWidth)];
z = conv(x,x);
figure(3);
subplot(2, 1, 1);
plot(t2, z);
xlabel('t');
ylabel('z(t)');
title('Figure 4: Time Domain');
grid on;
z_ift = ifft (Zf);
subplot(2, 1, 2);
plot(t2, z_ift);
xlabel('t');
ylabel('z(t)');
title('Figure 5: Frequency Domain');
grid on;
```

The MATLAB results were the same as the result of A.1. The Fourier Transform property demonstrated is that the time-domain convolution of two functions is equal to the product in the frequency-domain of the Fourier Transforms of those two functions.

A.5)

```
N = 100; PulseWidth = 5; %change between 5, 10, and 25 to check each FT
t = [0:1:(N-1)];
x = [ones(1,PulseWidth), zeros(1,N-PulseWidth)];
Xw = fft(x);
f = [-(N/2):1:(N/2)-1]*(1/N);
w = 2*pi*f;
figure(4);
subplot(2,1,1);
plot(f,fftshift(abs(Xw)));
grid on;
xlabel('t');
ylabel('Magnitude');
title('Figure 6: z(t) Magnitude Spectra');
subplot(2,1,2);
plot(f,fftshift(angle(Xw)));
grid on;
xlabel('t');
ylabel('Magnitude');
title('Figure 7: z(t) Phase Spectra');
```

a)

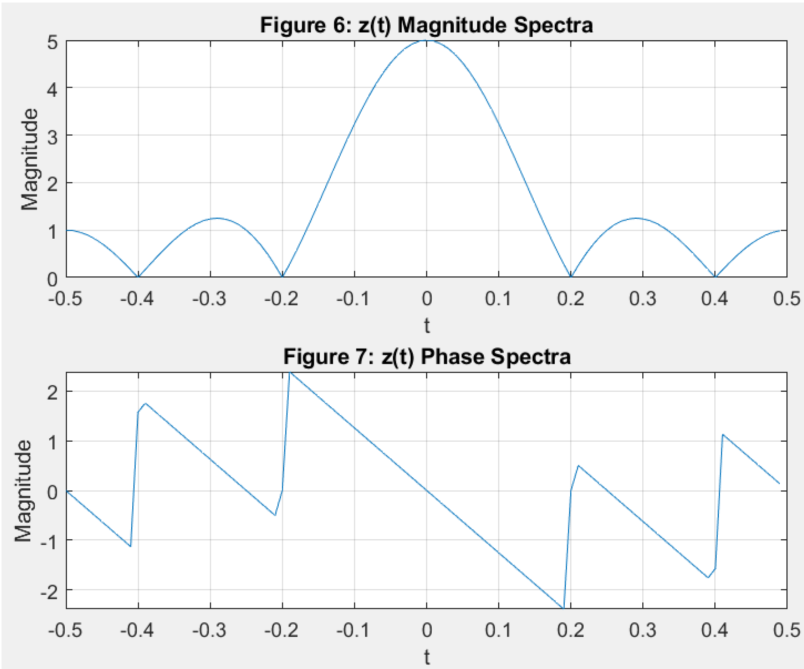


Figure 6: z(t) Magnitude Spectra
Magnitude
t
Figure 7: z(t) Phase Spectra
Magnitude
t

b)

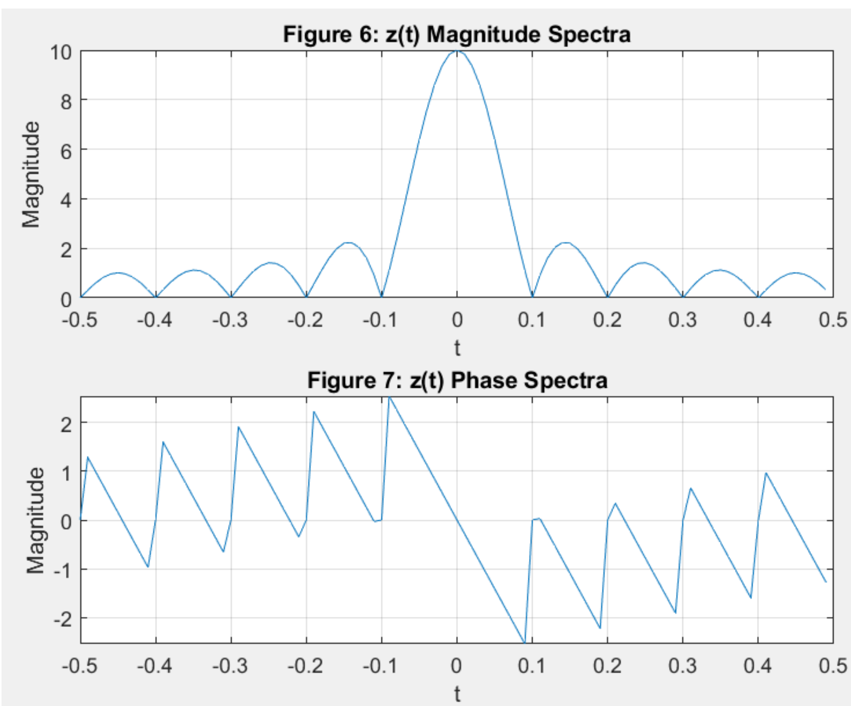
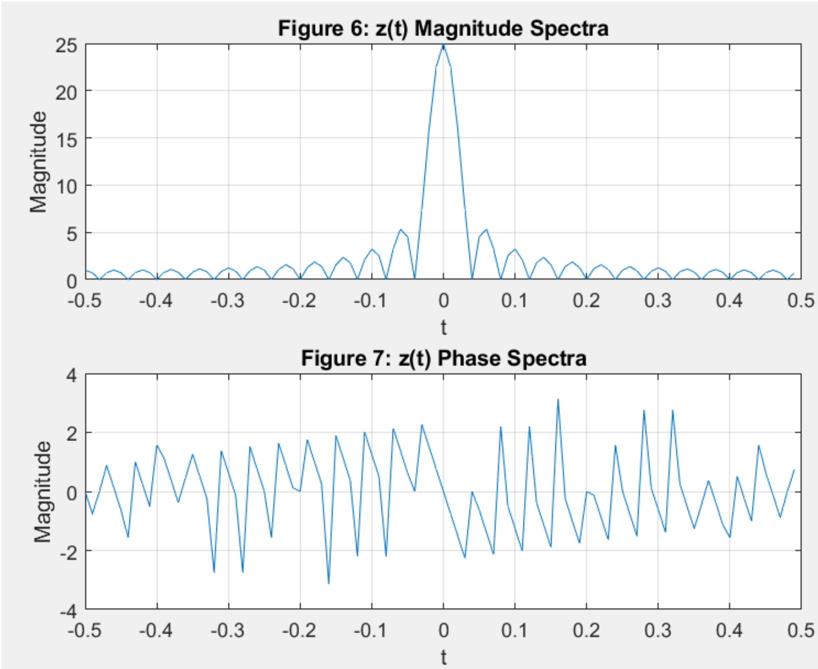


Figure 6: z(t) Magnitude Spectra
Magnitude
t
Figure 7: z(t) Phase Spectra
Magnitude
t

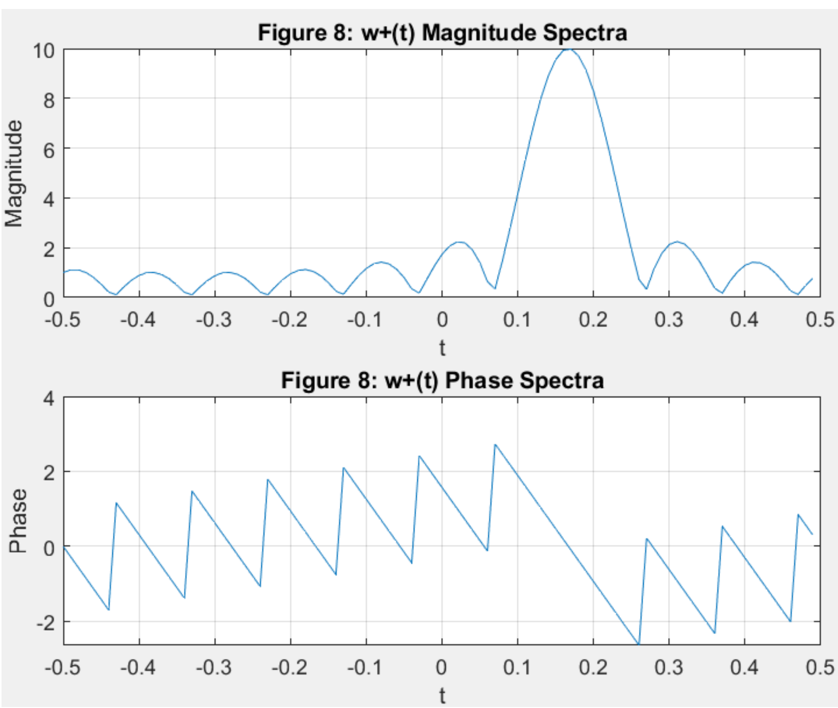
c)



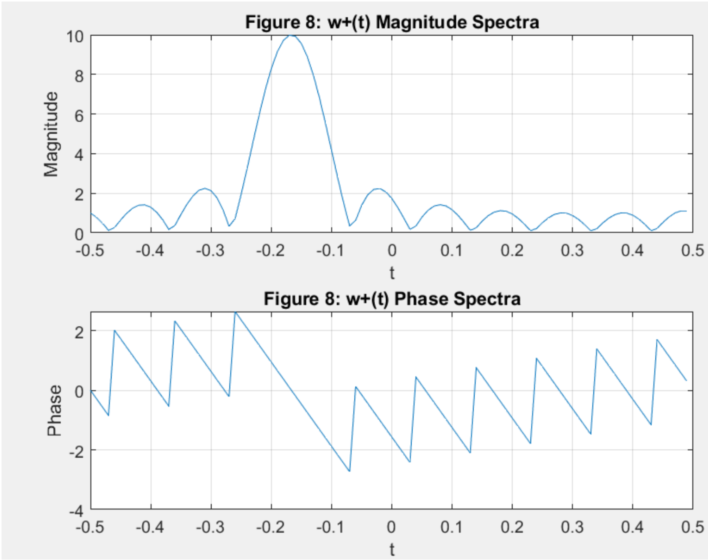
As we transition from pulse width 5 to 10 to 25, the magnitude and frequency spectra become more frequent and as a result, they come closer together. As the pulse width of the original function increases, the amplitude and frequency of the Fourier Transform increases and vice versa. This is known as the time-scaling property of the Fourier Transform.

<u>A.6)</u>
<u>a)</u>

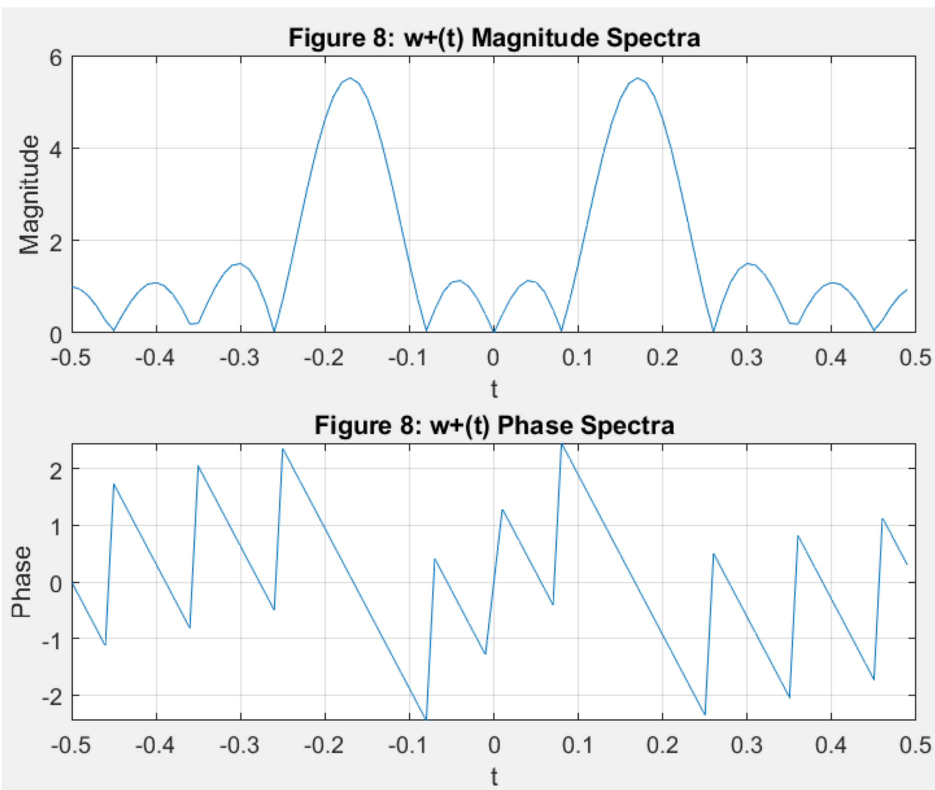
```
N = 100; PulseWidth = 10;
t = [0:1:(N-1)];
x = [ones(1,PulseWidth), zeros(1,N-PulseWidth)];
f = [-(N/2):1:(N/2)-1]*(1/N);
wt = x.*(exp(1j*(pi/3).*t));
%wt = x.*(exp(-1j*(pi/3).*t));
%wt = x.*cos((pi/3).*t);
Ww = fft(wt);
figure;
subplot(2,1,1);
plot(f,fftshift(abs(Ww)));
grid on;
xlabel('t');
ylabel('Magnitude');
title('Figure 8: w+(t) Magnitude Spectra');
subplot(2,1,2);
plot(f,fftshift(angle(Ww)));
grid on;
xlabel('t');
ylabel('Phase');
title('Figure 8: w+(t) Phase Spectra');
```



b)



c)

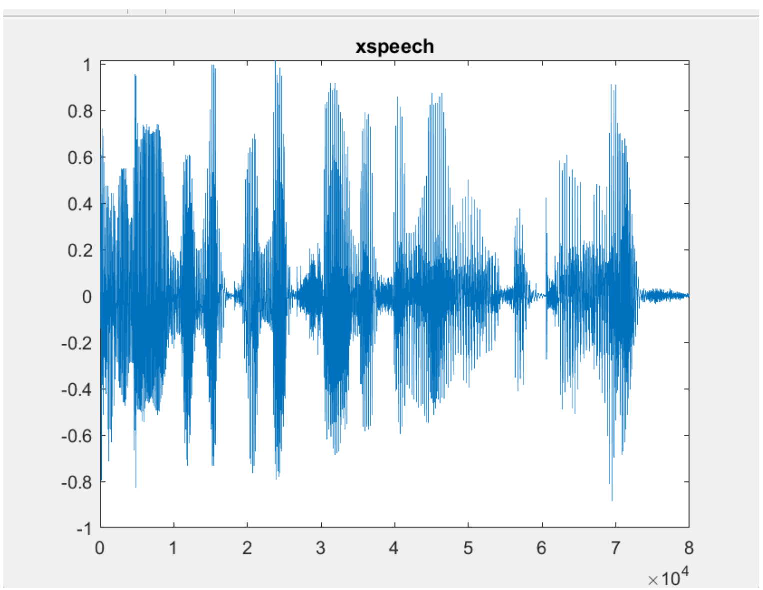


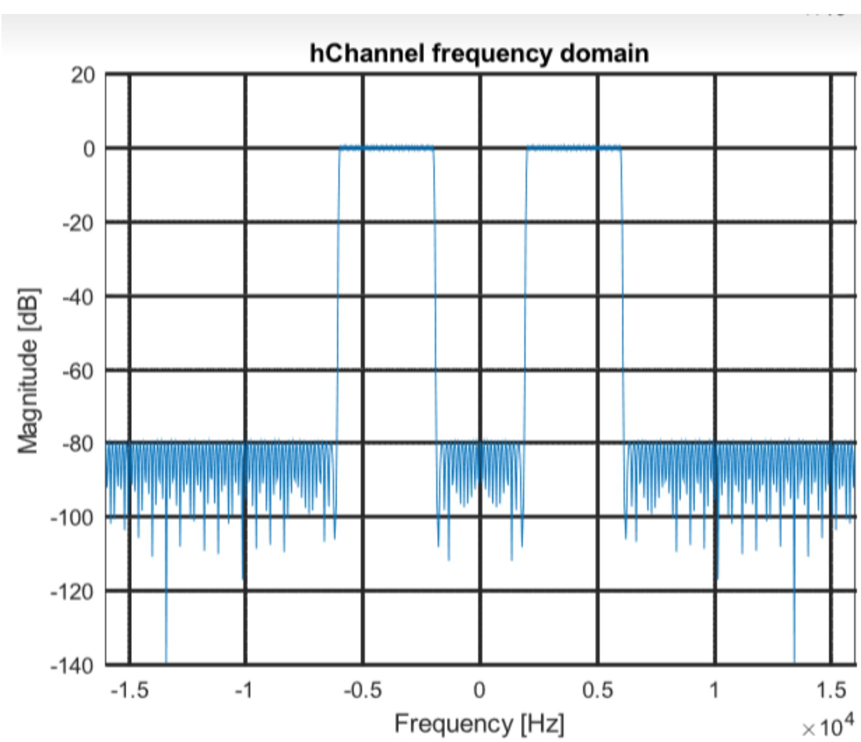
When the original function was multiplied with a complex multiple, there was a shift in the frequency. The property demonstrated is Frequency Shift, which shows that a shift in the frequency domain can be caused by multiplying the time-domain function by an exponential function, since cosines can be represented in Euler form the above statement holds true.

Assignment B:

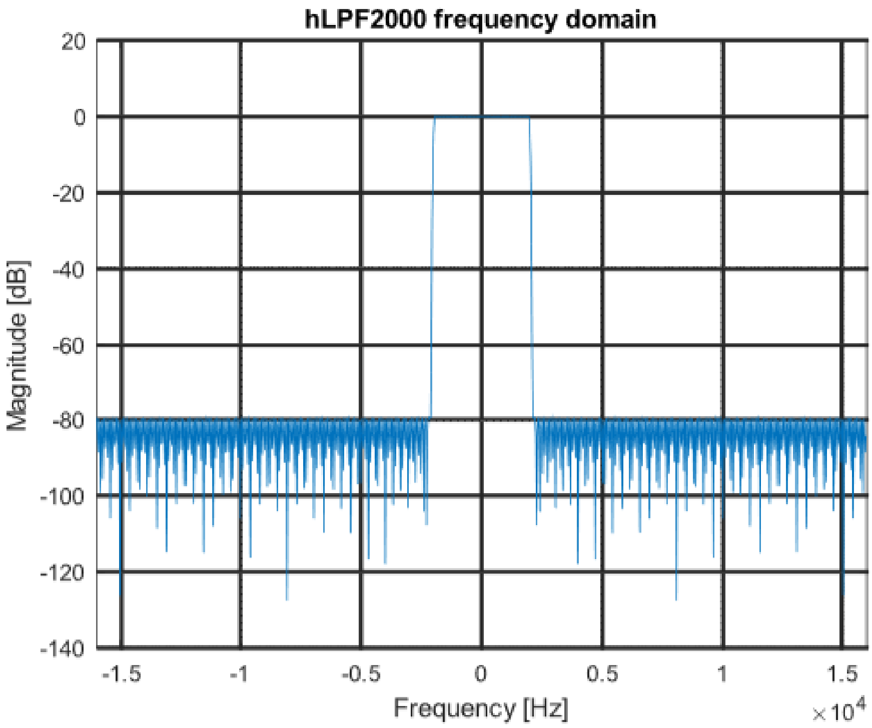
B.1)

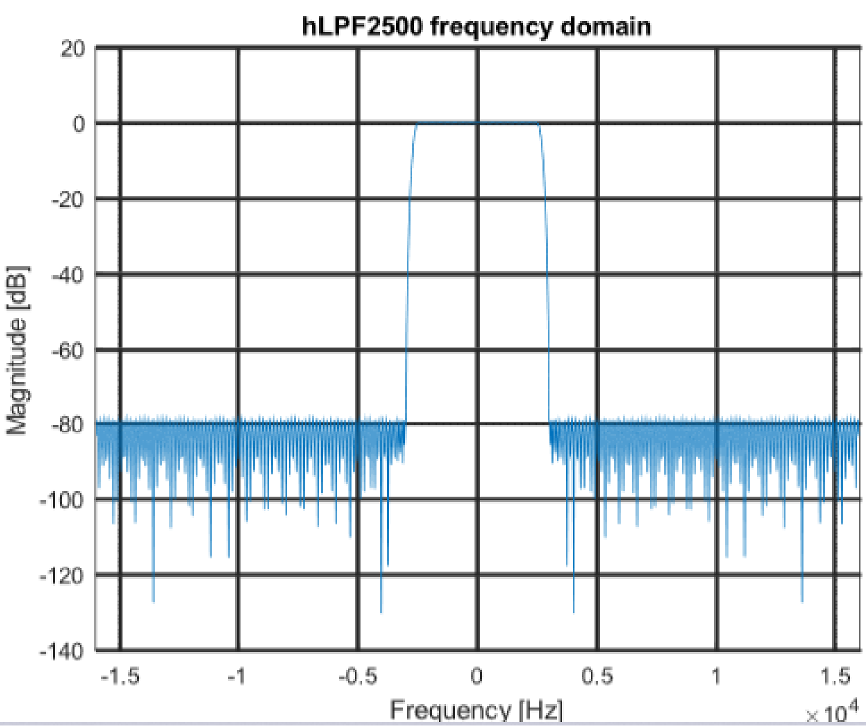
```
load('Lab4_Data.mat');

figure(1)
plot(xspeech)
title('xspeech');

figure(2)
MagSpect(hChannel)
title('hChannel Freq Domain');

figure(3)
MagSpect(hLPF2000)
title('hLPF2000 Freq Domain');

figure(4)
MagSpect(hLPF2500)
title('hLPF2500 Freq Domain');
```





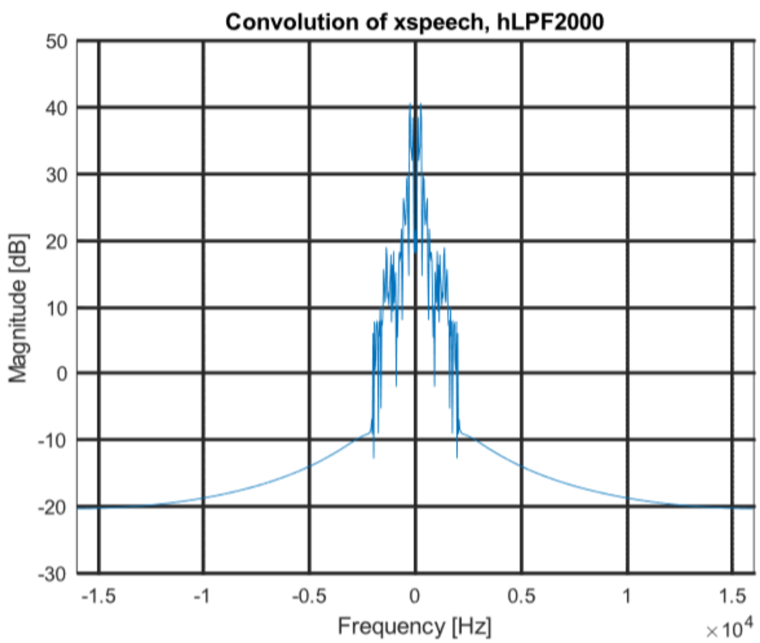
hChannel frequency domain
Magnitude [dB]
20
0
-20
-40
-60
-80
-100
-120
-140
-1.5
-1
-0.5
0
0.5
1
1.5
Frequency [Hz]
$\times 10^4$

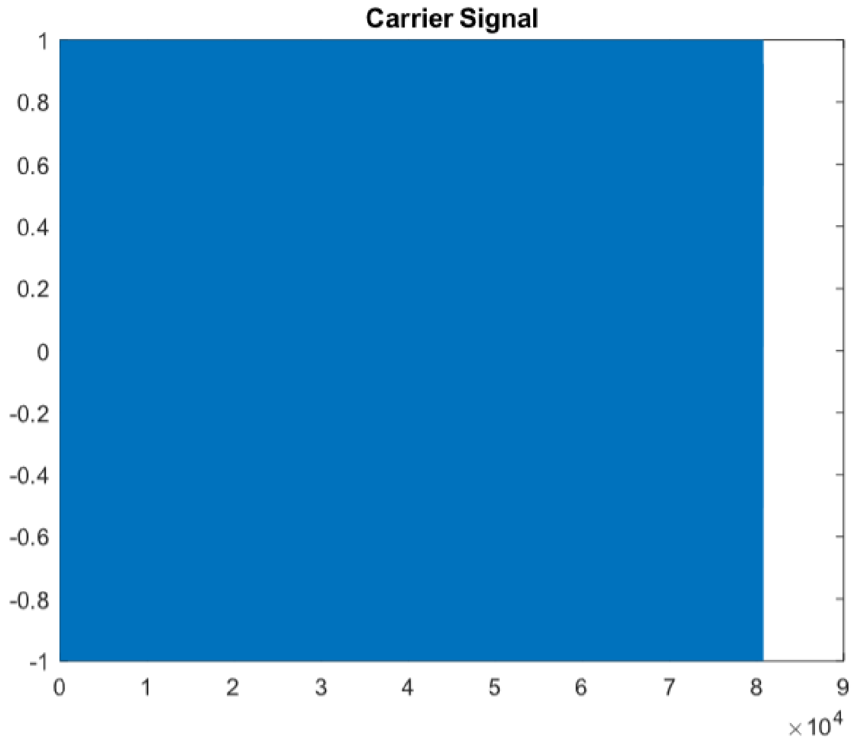

hLPF2000 frequency domain
Magnitude [dB]
Frequency [Hz]
$\times 10^4$

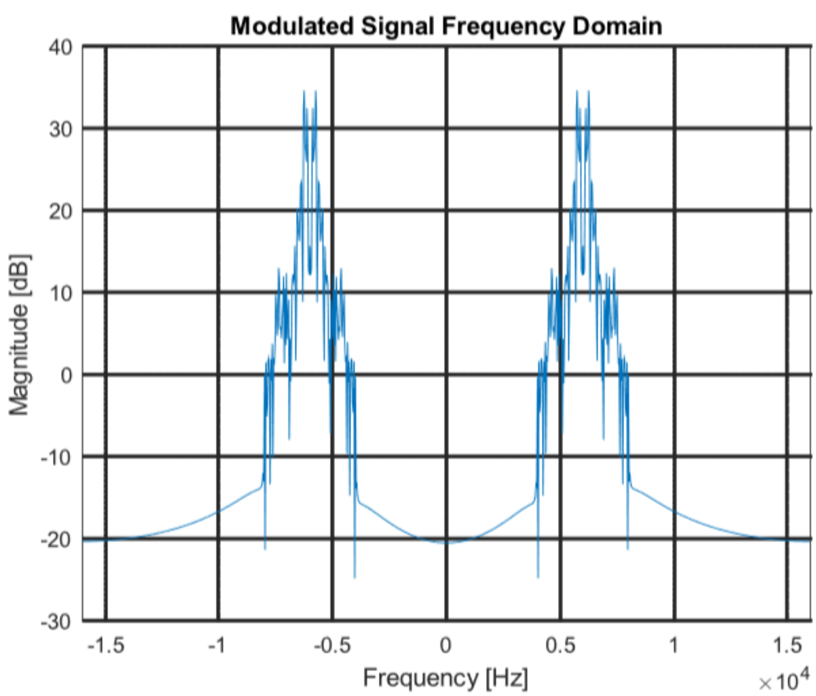

hLPF2500 frequency domain
Magnitude [dB]
Frequency [Hz]
$\times 10^4$

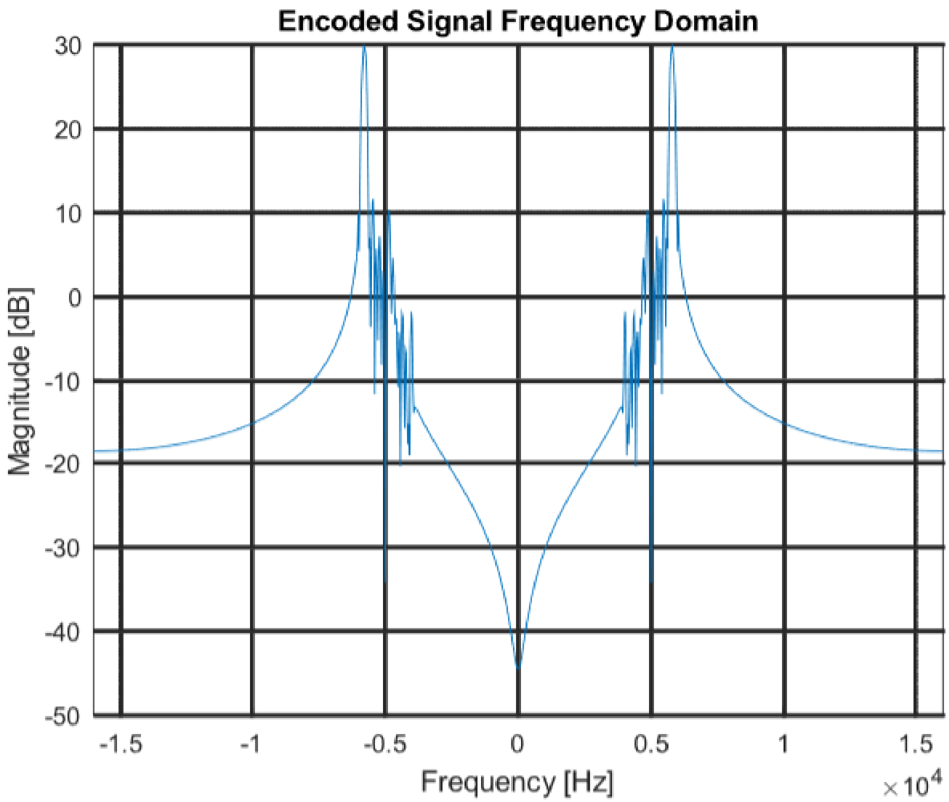
b)

```
conv1 = conv(xspeech, hLPF2000);
figure(5)
MagSpect(conv1)
title('Convolution of xspeech and hLPF2000');
carrier = osc(6000,80710,32000);
figure(6)
plot(carrier)
title('Carrier Signal');
Mod = conv1.*carrier;
figure(7)
MagSpect(Mod)
title('Modulated Signal Frequency Domain');
Output = conv(Mod, hChannel);
figure(8)
MagSpect(Output)
title('Encoded Signal Frequency Domain');
```



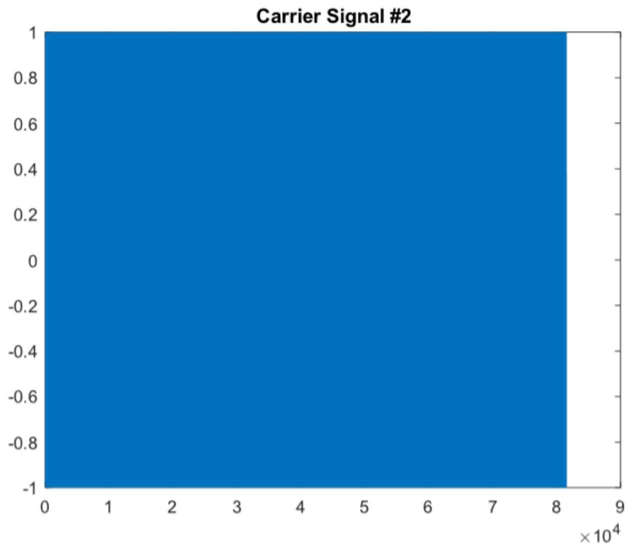

Carrier Signal
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0 1 2 3 4 5 6 7 8 9
$\times 10^4$

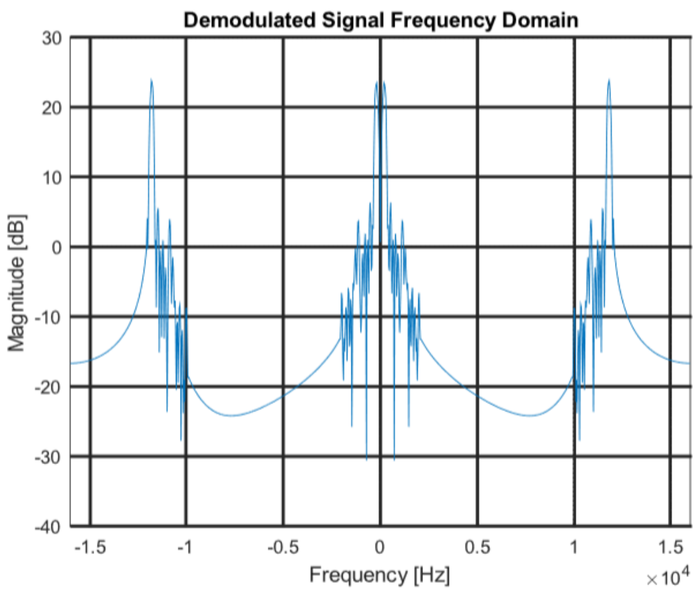

Modulated Signal Frequency Domain
40
30
20
10
0
-10
-20
-30
Magnitude [dB]
-1.5 -1 -0.5 0 0.5 1 1.5
Frequency [Hz]
$\times 10^4$

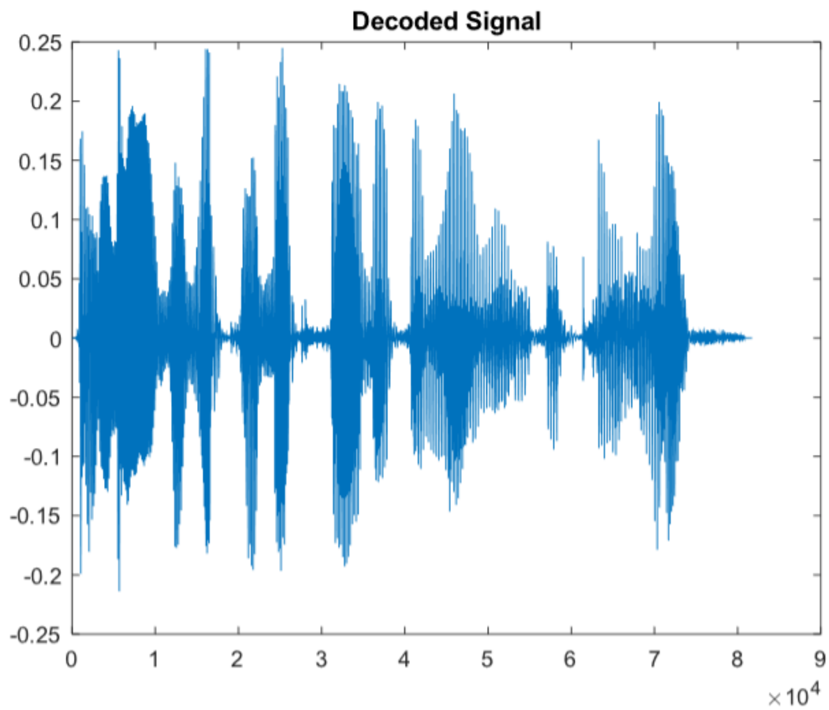


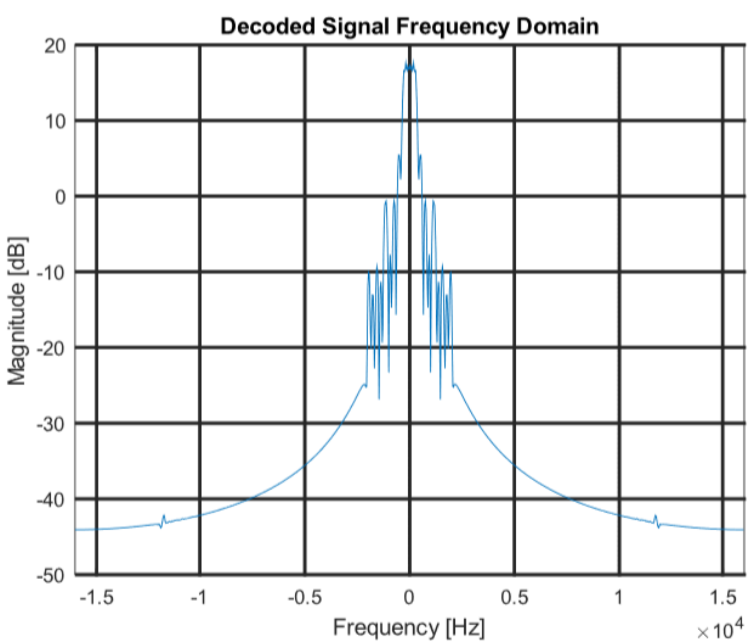
c)

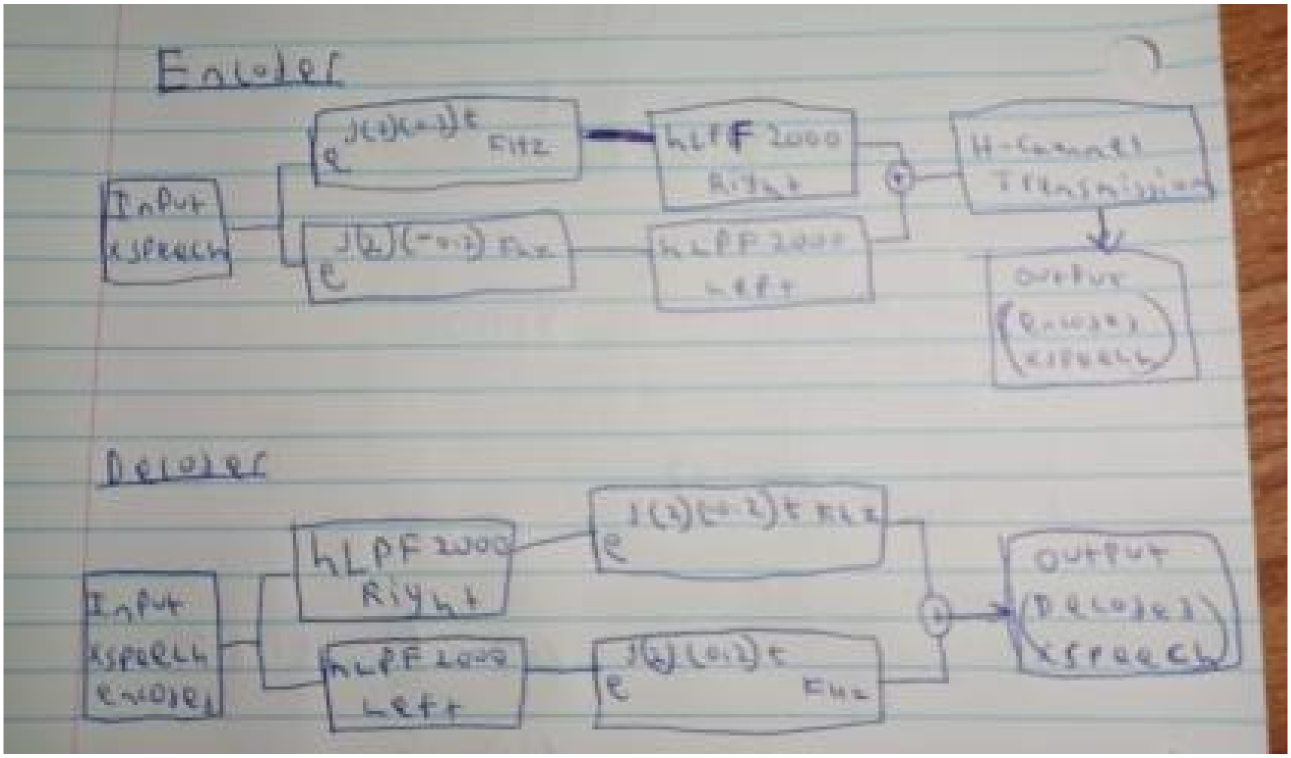
```
% Decoder
carrier2 = osc(6000,81520,32000);
figure(9)
plot(carrier2)
title('Carrier Signal #2');
Demod = Output.*carrier2;
figure(10)
MagSpect(Demod)
title('Demodulated Signal Frequency Domain');
recover_xspeech = conv(Demod, hLPF2500);
figure(11)
plot(recover_xspeech)
title('Decoded Signal');
figure(12)
MagSpect(recover_xspeech)
sound(recover_xspeech,32000)
title('Decoded Signal Frequency Domain');
```


Carrier Signal #2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0 1 2 3 4 5 6 7 8 9
×10^4


Demodulated Signal Frequency Domain
Magnitude [dB]
30
20
10
0
-10
-20
-30
-40
-1.5 -1 -0.5 0 0.5 1 1.5
Frequency [Hz]
×10^4


Decoded Signal
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
1
2
3
4
5
6
7
8
9
$\times 10^4$


Decoded Signal Frequency Domain
Magnitude [dB]
20
10
0
-10
-20
-30
-40
-50
-1.5
-1
-0.5
0
0.5
1
1.5
Frequency [Hz]
$\times 10^4$


Encoder
Input
Right
Left
Output
Decoder
Input
Right
Left
Output